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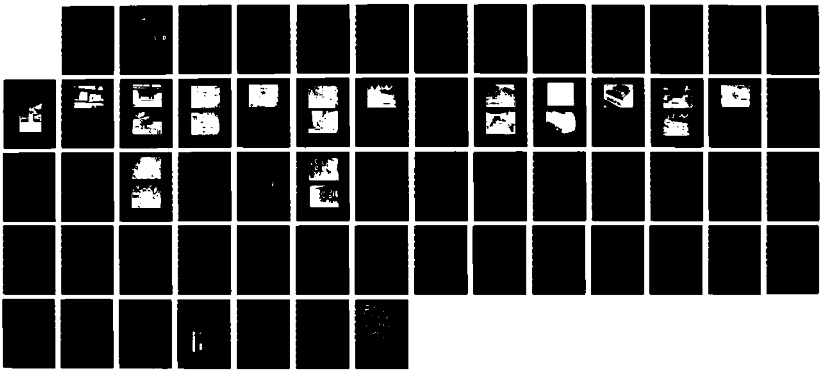

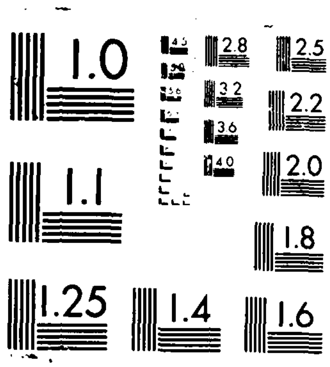
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REPORT NO. NADC-87162-60

AD-A189 366

HYDRAULIC DIAGNOSTICS AND FAULT ISOLATION TEST PROGRAM

Grumman Aircraft
Systems Division
Bethpage, NY 11714-3341

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February 1987

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Air Task A511-001-C/601142-000

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Prepared for
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The hydraulic diagnostic and fault isolation test program investigated the feasibility of detecting and isolating a hydraulic failure in order to prevent loss of the entire system. Isolation valves were installed as a means of separating the subsystems from the main system. Various sensors were used to detect change in flow, temperature, pressure and reservoir level. The sensor information was fed to a microprocessor which compared the information to known parameters. In the event of failure detection, a signal was transmitted to the appropriate subsystem isolation valve which then shut off the subsystem from the main system.

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SUMMARY

The objective of the Hydraulic Diagnostics and Fault Isolation Test Program was to demonstrate and evaluate the practicality of a fault detection and isolation system on an aircraft. The diagnostics tests were performed on an 8000-psi hydraulic simulator. The three branch circuits of the simulator were modified to incorporate the various sensors and valving necessary to perform the tests required.

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FOREWORD

The Hydraulic Diagnostics and Fault Isolation Program was conducted by the Grumman Aircraft Systems, Mechanical System Design Section, Russell H. Hagerman, Section Head, under U.S. Navy contract number N62269-84-C-0289.

The project was administered by the Naval Air Development Center, Warminster, PA, with Mr. Anthony DeGennaro as Contract Monitor.

The work herein was conducted from September 1984 to July 1986.

Acknowledgements are given to the following individuals for their assistance and support in this test effort:

Edwin Anderson	Fluid Power Group Head
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Robert Kennedy	Mechanical/System Test
Joel Kesselman	Electronic & Electronic Design
Joe Pellegrino	Fluid Power Engineering
Peter Yau	Electronic & Electronic Design
Artie Wieder	Mechanical Design Technician

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ILLUSTRATIONS

1 - INTRODUCTION

Aircraft Hydraulic System Diagnostics and Fault Isolation for advanced fighter attack type aircraft are a necessary evolution due to growing vehicle complexity. The hydraulic diagnostics and fault isolation is a monitoring system capable of fault detection and isolation in a hydraulic subsystem through the use of sensors and a microprocessor (Fig. 1). The microprocessor is programmed to direct hydraulic shutdown of a failed subsystem through the use of isolation valves.

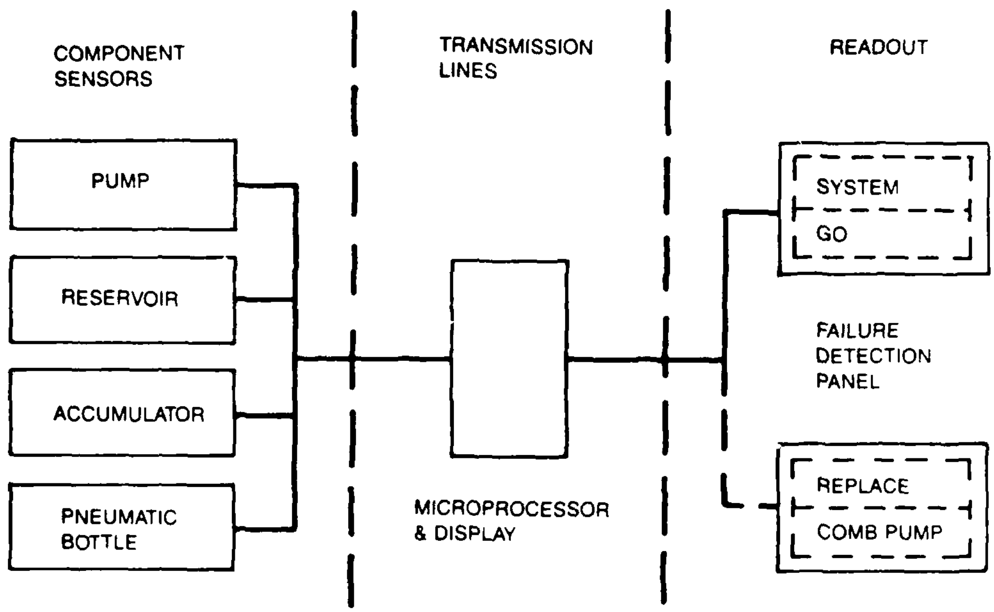


Figure 1. Hydraulic Diagnostics & Fault Isolation Block Diagram.

Various modes of failure were investigated in order to demonstrate the capability of the microprocessor to evaluate the malfunction and the isolation valves to effectively shut down the faulty subsystem.

The tests (see Appendix A) investigated were as follows:

- External Leak Detection - high subsystem flow, display and isolation
- External Leak Detection - low subsystem flow, display and isolation
- Internal Leak Detection - increased subsystem flow, display and isolation
- Servo Actuator Detection - open loop failure, display and isolation
- Case Drain Flow Detection - excessive pump case drain flow, detection and display
- Excessive air in system, detection and display
- Excessive pump case drain temperature, detection and display.

2 - TECHNICAL DISCUSSION

2.1 DESCRIPTION OF HYDRAULIC SYSTEM SIMULATOR

The fault detection and isolation test arrangement consisted of a high pressure, lightweight aircraft hydraulic system simulator with three separate branch circuits (see Appendix B). The three branch circuits operated at 8000 psi and were supplied by one 14-gpm, 8000-psi aircraft hydraulic pump which was driven by a 75-hp electric vari-drive unit.

Each branch circuit consisted of an 8000-psi hydraulic actuator opposed by a load cylinder which simulated the flight loads encountered by an aircraft flight control system. There were also two electrohydraulic servovalves and one three-position solenoid valve which were used to control the cycling of the high pressure actuators. Two of the three hydraulic system branch circuits employed the servovalves, and the third circuit used the solenoid valve. The components of the branch circuits consisted of 8000-psi relief valves, an accumulator, check valves, quick disconnect fittings, filters, and flex hoses. Other components included heat exchangers, hydraulic swivels, coiled tube assemblies, and titanium fittings and tubing. A bellows type reservoir was used. Linear Variable Differential Transformers (LVDTs) were used in conjunction with the servovalves for two purposes: one LVDT to mark the position of the actuator piston and two LVDTs to maintain a closed loop by providing a feedback.

2.2 INSTRUMENTATION

Instrumentation consisted of a 25,000 lb force link attached to the piston rod of the load cylinder; a 20,000 psi pressure transducer at the pump outlet pressure to the test rigs; flow measuring of pump outlet, pump case drain, and other pertinent flows; an assortment of pressure gages and thermocouples; and pressure, flow, and temperature recorders.

All components were tested on a Grumman Aircraft Systems Division high pressure test bench to the appropriate proof pressures (12,000 psi and 16,000 psi) before being installed. On the simulator all tests were conducted using MIL-H-83282 hydraulic fluid. Data sheets are available upon request.

Figure 2 shows brush chart recorders used to monitor piston position, inlet flow to each rig, inlet pressures, case drain flow, and reservoir level. Appendix C shows a sample of the brush chart recording printout. Figure 3 shows the non-intrusive flow sensor digital display panel. The brush chart recording readout provides a correlation for the subsystem flow sensor digital display. Figure 4 a and b illustrates the control panel for the isolation valves, temperature readouts, and the closed loop system interact unit.

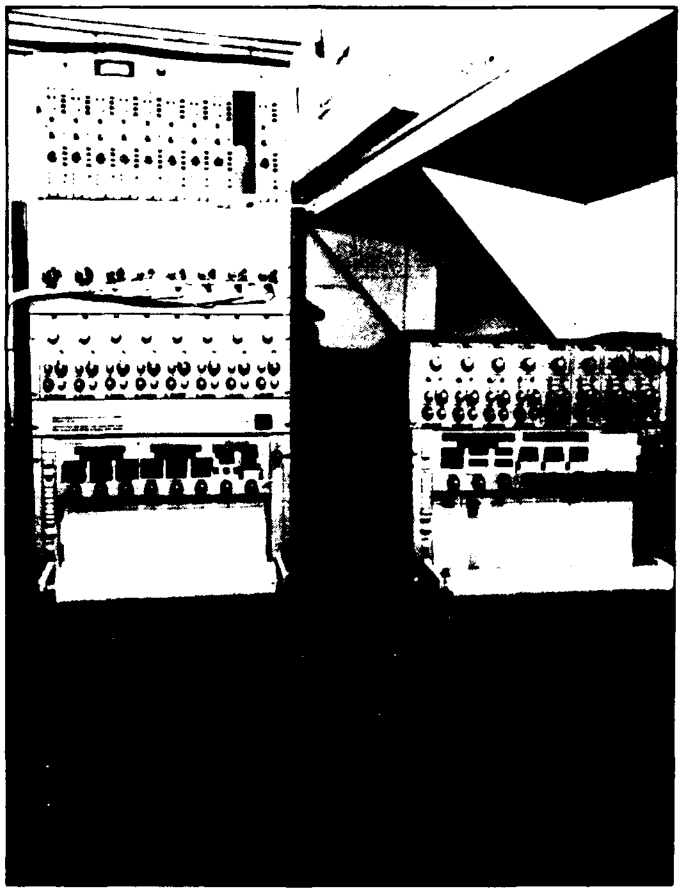


Figure 2. Brush Chart Recorders.

2.3 ISOLATION VALVE

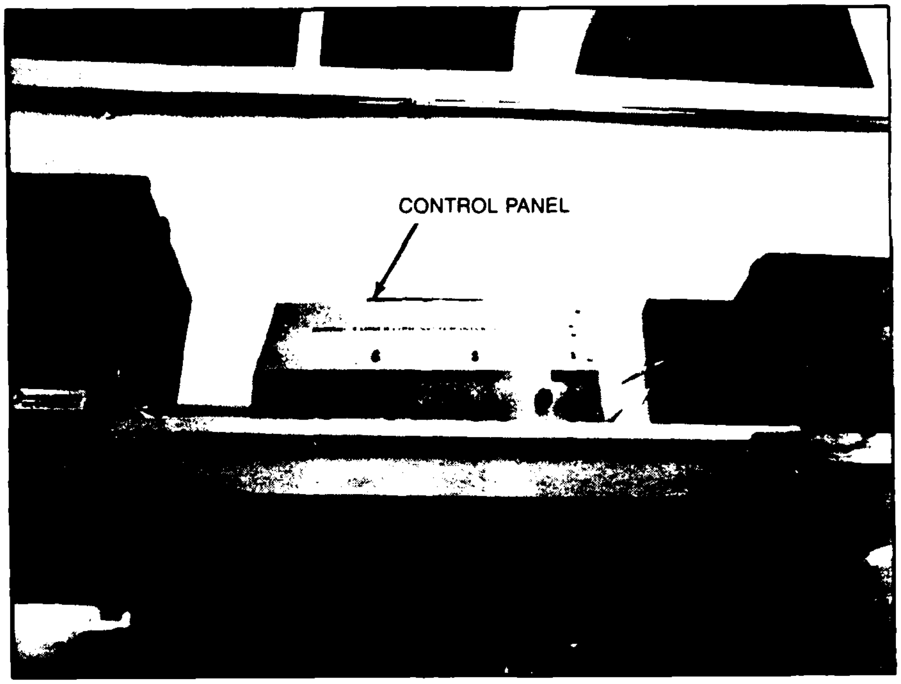
The 8000-psi hydraulic simulator used three isolation valves (Fig. 5). Each branch circuit had its own isolation valve. The isolation valves were installed in the supply line at the inlet to each branch test actuator valve. Two of the ports were

Figure 2. Flow Sensor Display.

utilized for supply and one for the solenoid vent to return. All three ports were on the same face of the valve. The supply ports were rated at 8000 psi and the return at 100 psi. The temperature range was -65°F to +275°F. Flow was rated at 5.7 gpm. A pressure drop of 50 psi was sustained at a flow rate of 5.7 gpm with a temperature range of 70°F to 100°F. Response time was 10 milliseconds. The valve operates at a voltage of 28 VDC with a minimum pull in voltage of 17 VDC at 70°F. Dropout occurs at a voltage level between 2 to 7 VDC. One ampere was the current flow when the valve was operating at 29 VDC and 70°F.

2.4 INTERNAL LEAK VALVE

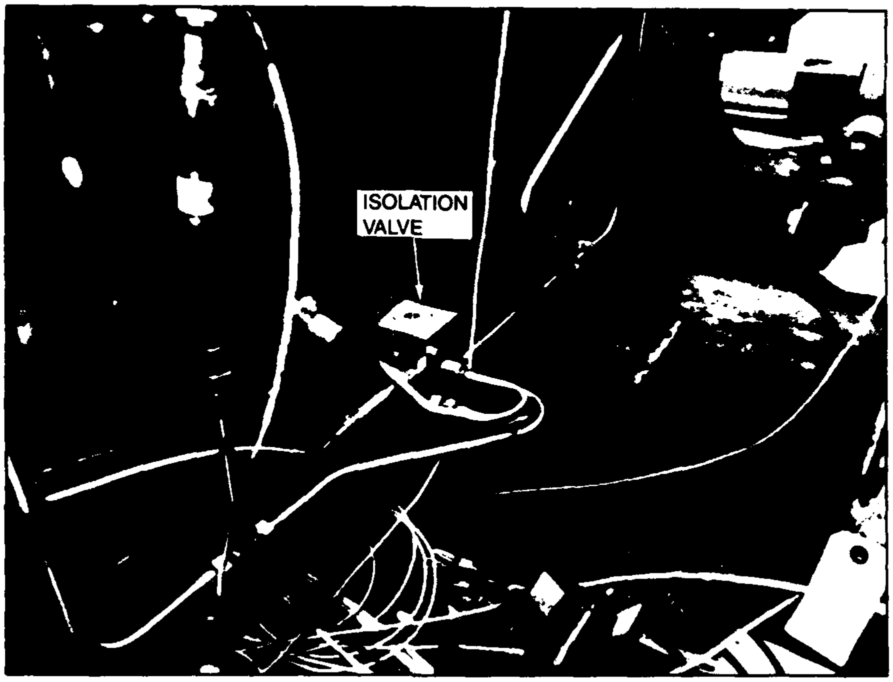
Internal leakage was simulated using two valves, the solenoid valve and a manual valve (Fig. 6 a and b). The direction of flow can be in either direction depending on actuator stroke. Internal leakage was used as a fault mechanism to trigger diagnostic sensors. The hand valve simply sizes the leak. The solenoid valve operated at 8000 psi with a return pressure of 100 psi and no external leakage. Internally, whether de-energized or energized, leakage from a pressure port to a return port was a maximum of two drops per minute. Normal operating temperatures ranged from 140°F to 180°F. The extreme temperature range was -50°F to 275°F. Voltage during operation was from 17 VDC to 30 VDC. Current reached a



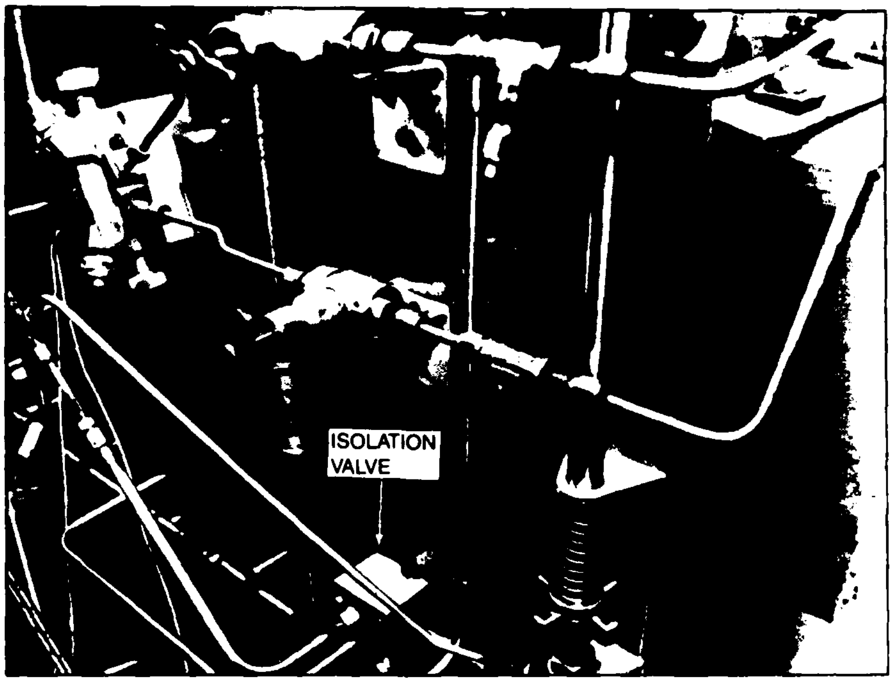
a.

b.

Figure 4. Control Panel.

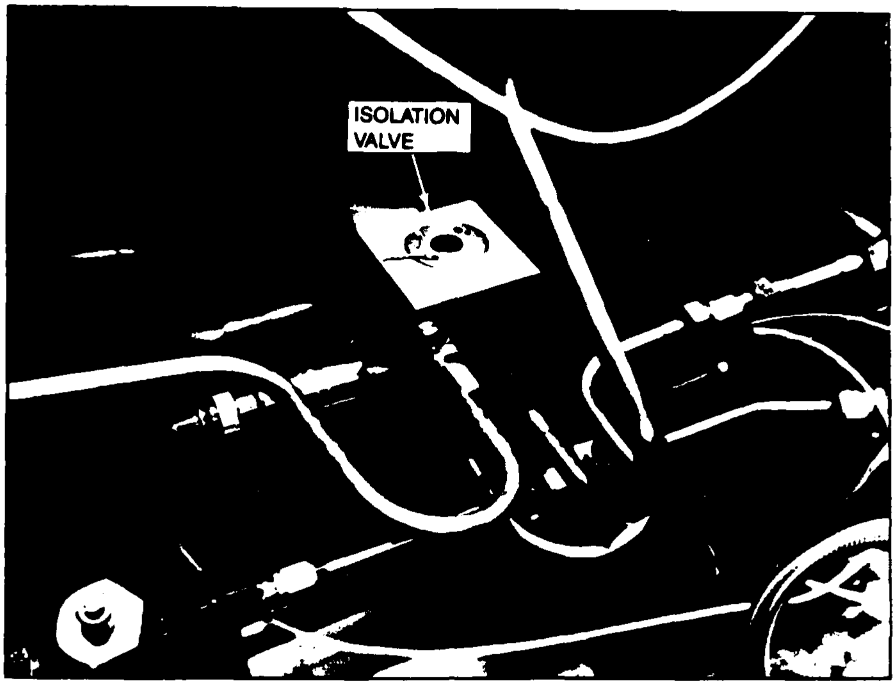


a. No. 1



b. No. 2

Figure 5. Isolation Valve Branch Circuit (Sheet 1 of 2).



c. No. 3

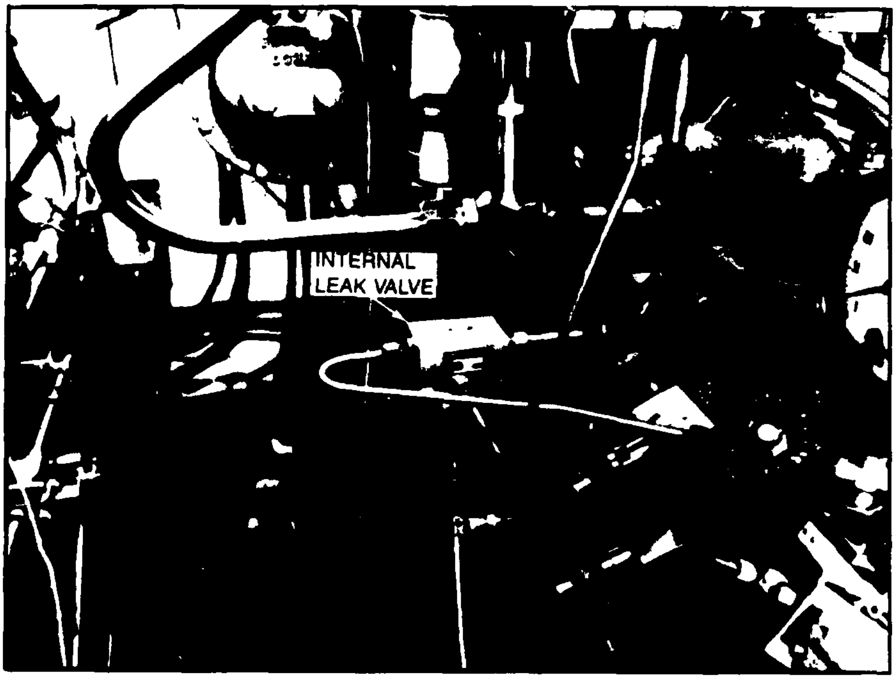
Figure 5. Isolation Valve Branch Circuit (Sheet 2 of 2).

maximum of 0.75 amperes with 30 VDC and 70°F. Both branch circuits No. 2 and No. 3 have a simulated internal leakage valve.

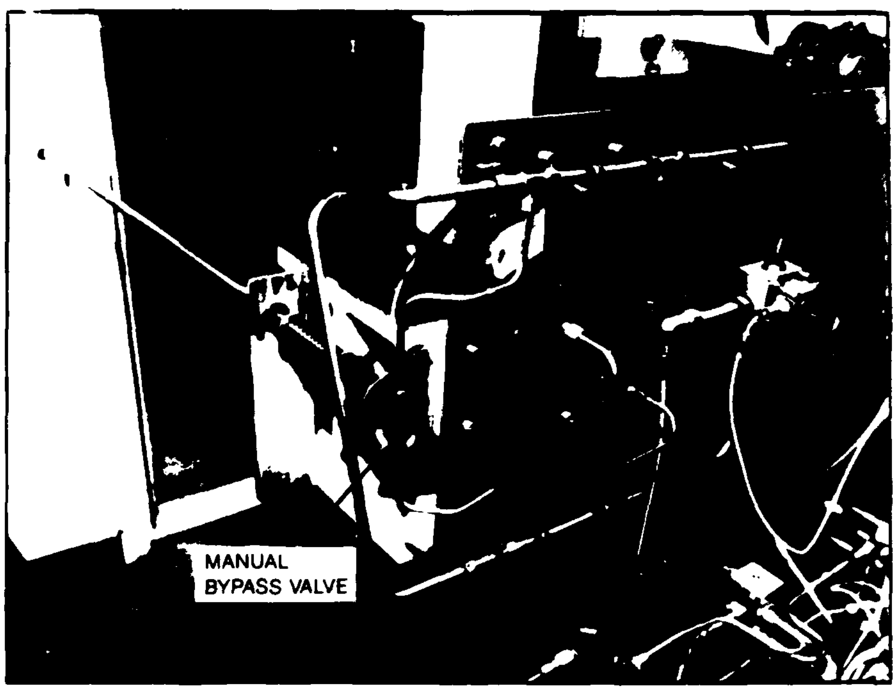
2.5 EXTERNAL VALVE

An external leakage valve (Fig. 7) was used as a fault mechanism to activate hydraulic sensors. Located on the supply line, the solenoid valve was used with a hand valve to size the leak and initiate an external leak. The solenoid valve was fabricated with three ports, each on a face of the valve. Internal leakage at the pressure port was one drop for every three minutes, whether de-energized or energized, with the cylinder port blocked. External leakage was zero. Normal operating temperature was between 140°F and 180°F. The extreme allowable temperature range was from -50°F to +275°F. The operating voltage was between 17 VDC and 30 VDC. The current draw was 0.75 amperes with a maximum of 30 VDC and 70°F.

Branch circuits No. 1 and No. 3 each had an external leakage valve.



a. INTERNAL LEAK VALVE



b MANUAL BYPASS VALVE

Figure 6. Internal Leakage.

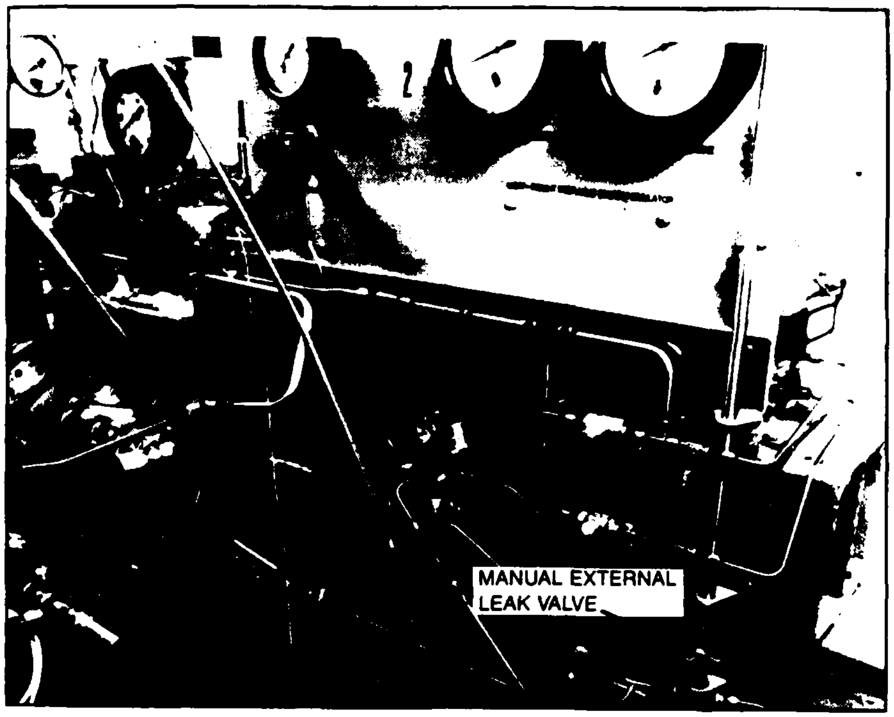


Figure 7. Manual External Leak Valve.

2.6 RESERVOIR LEVEL SENSING

The hydraulic simulator utilized a bellows reservoir with provisions for direct digital level reading through a viewing plug. The bellows reservoir was modified for the hydraulic diagnostics and fault isolation program to accommodate a reservoir level sensor (Fig. 8 and 9). The reservoir level sensor was mounted to the end cap of the bellows and hard wired to the microprocessor. This provided for a continuous updating of the reservoir's piston position during operation.

2.7 DISPLAY PANEL

An alphanumeric display panel (Fig. 10) developed with in-house funding and related to the Hydraulic Universal Display Processor System under contract number N62264-81-C-0243 was used for the hydraulic diagnostic and fault isolation program. In addition, a voice synthesizer (Fig. 11) operating on an ASCII code was used to provide an audio readout. A printer (Fig. 12) was tied into the system to provide a continuous printout during all modes of operation.

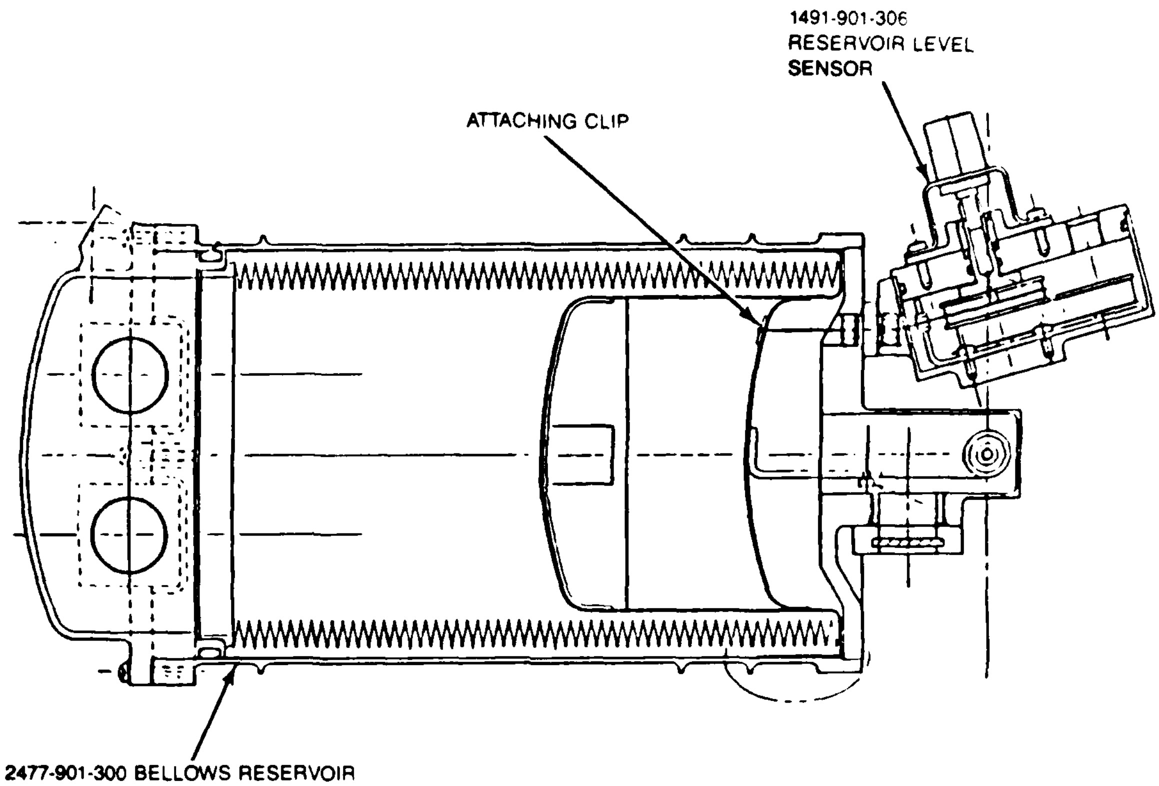


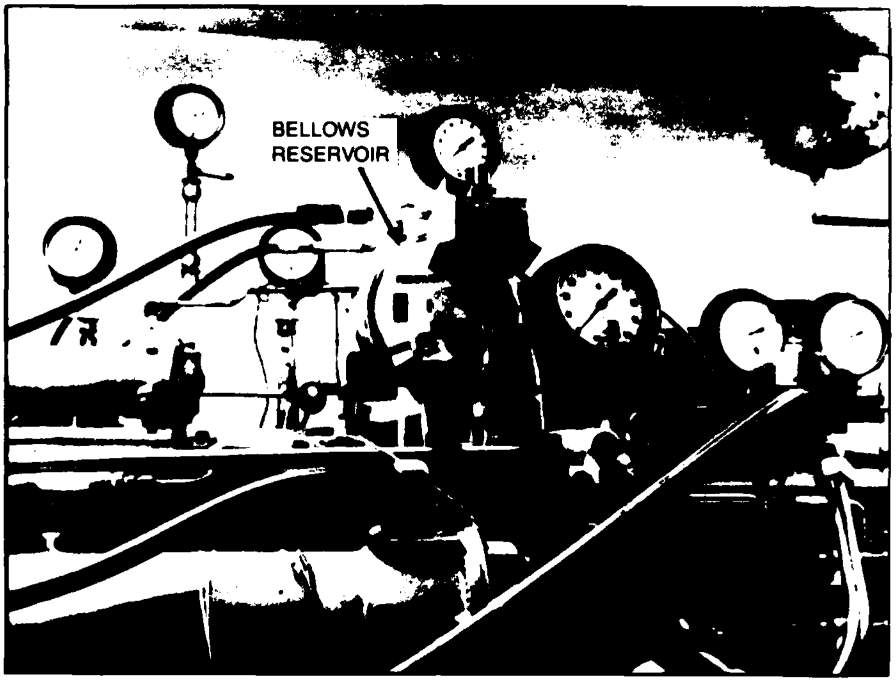
Figure 8. Bellows Reservoir.

2.8 FLUID TEMPERATURE

In order to monitor the large amount of heat generated during internal system leakage, temperature sensors were used for the system output flow, case drain flow, and reservoir return flow. Two types of sensors were used: an in-line sensor and a non-intrusive sensor (Fig. 13 a and b). The reservoir temperature was recorded using an in-line temperature sensor, and the information was displayed as a digital readout. The case drain and system output flow temperatures were recorded using non-intrusive sensors and were displayed as a digital readout. The case drain temperature was fed to the microprocessor as a fault detection and display failure mode.

2.9 FLOW SENSORS

The flow sensors (Fig. 14) used were the non-intrusive type which do not require modification to the existing system. They were used in the detection and isolation of a failed system. The normal operating environment of the system was established in order to provide the necessary baseline for the system. The location and sensitivity of the non-intrusive flow sensors were established to provide the necessary information during both normal system operation and when the failure modes were demonstrated.



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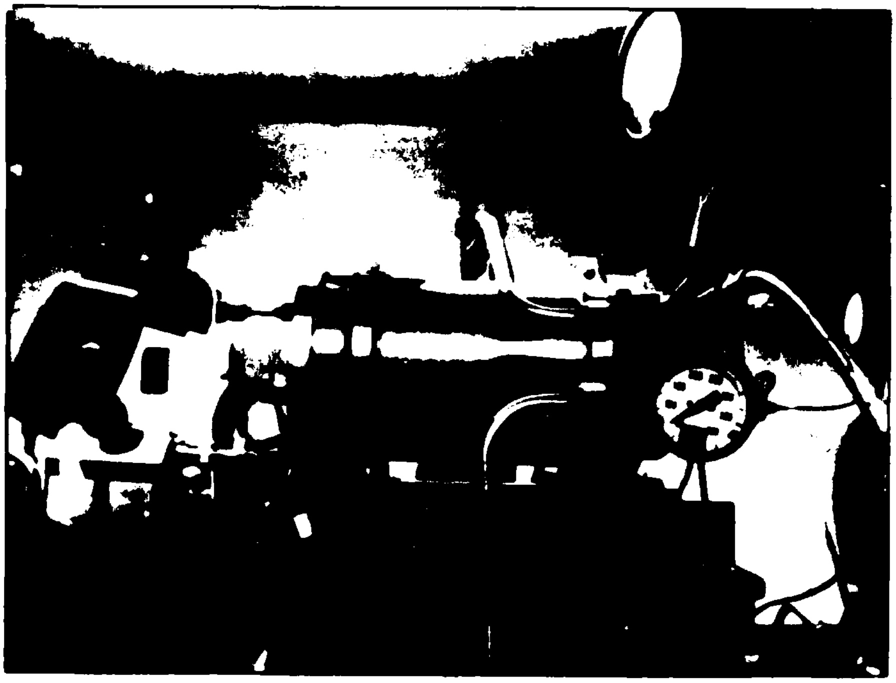

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Figure 9. Bellows Reservoir.

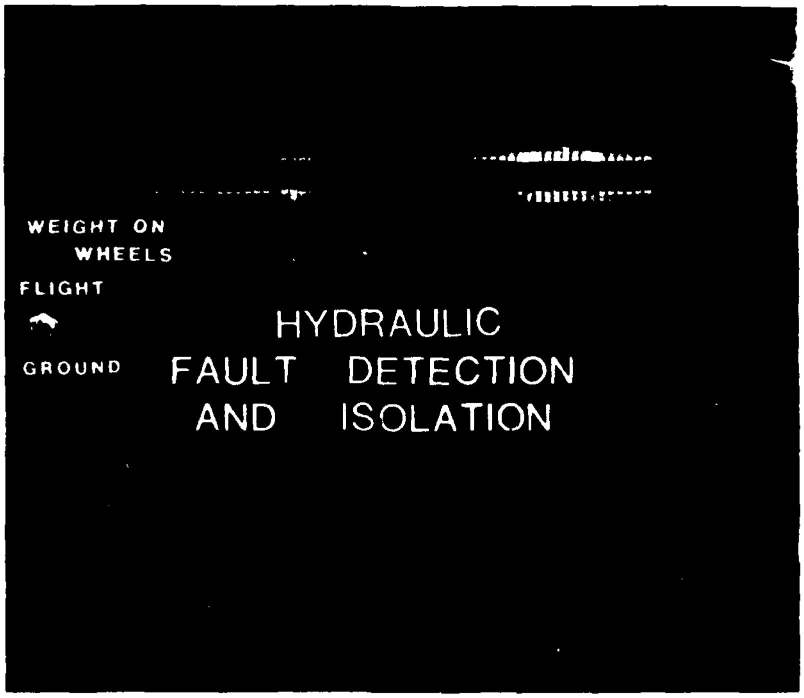


Figure 10. Display Panel.

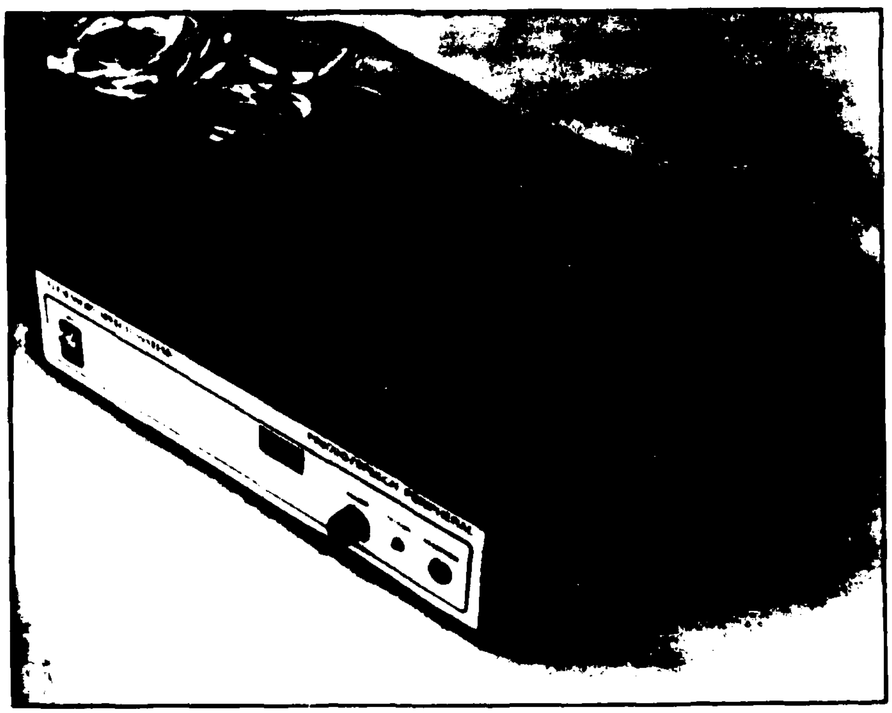


Figure 11. Voice Synthesizer.

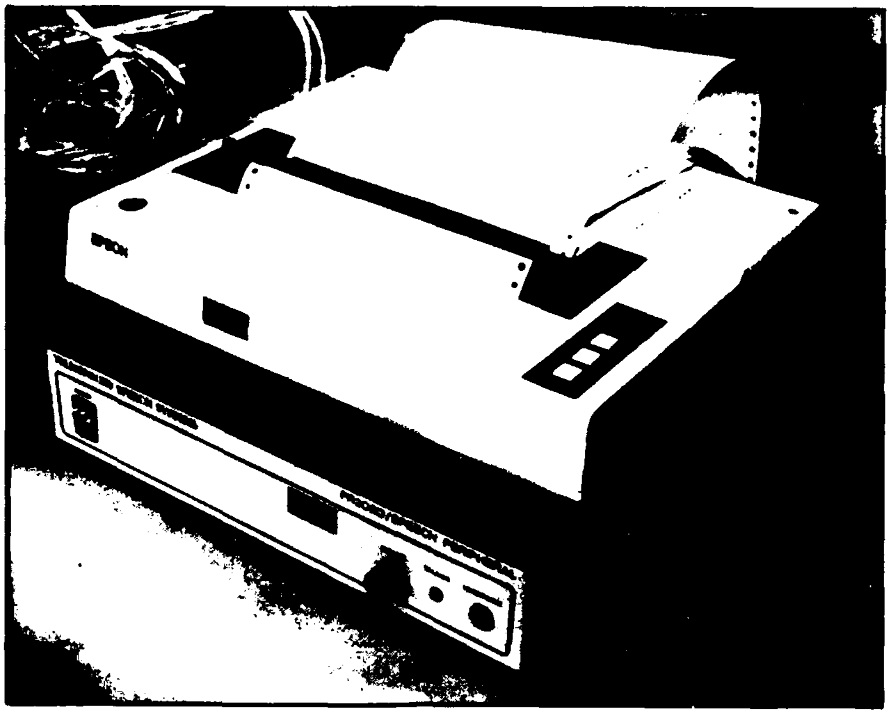


Figure 12. Printer.

2.10 TEST PROCEDURES

2.10.1 Subsystem External Leak Detection

The hydraulic branch circuit was modified to incorporate the following: external leak solenoid operated valve, a solenoid valve, pressure transducer, and non-intrusive flow sensor (Fig. 15). Initially, the external leak valve was to provide sufficient flow to establish high and low flow failure conditions. After several attempts at actuating the valve it was determined that repeatability was not possible. The external leak valve was returned to the manufacturer for rework in order to improve its reliability. Additional testing was performed to establish the limitations of the reworked external leak valve. The testing reinforced the inconsistency of the valve's performance. In order to prevent further delays with the operation of the external leak simulation, a manually operated bypass valve was installed to provide a means of simulating an external subsystem leak.

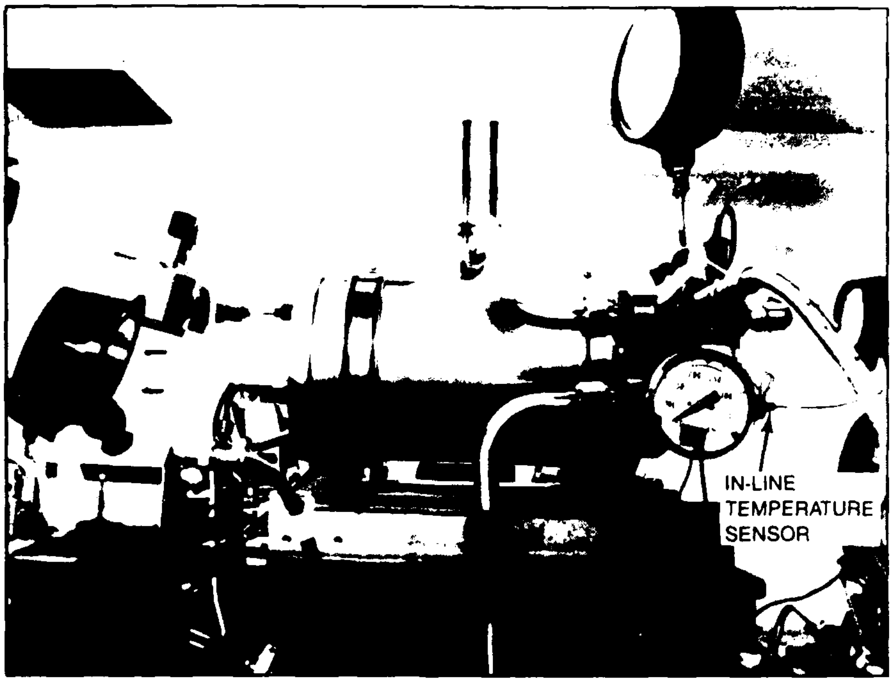


Figure 13a. In-Line Temperature Sensor

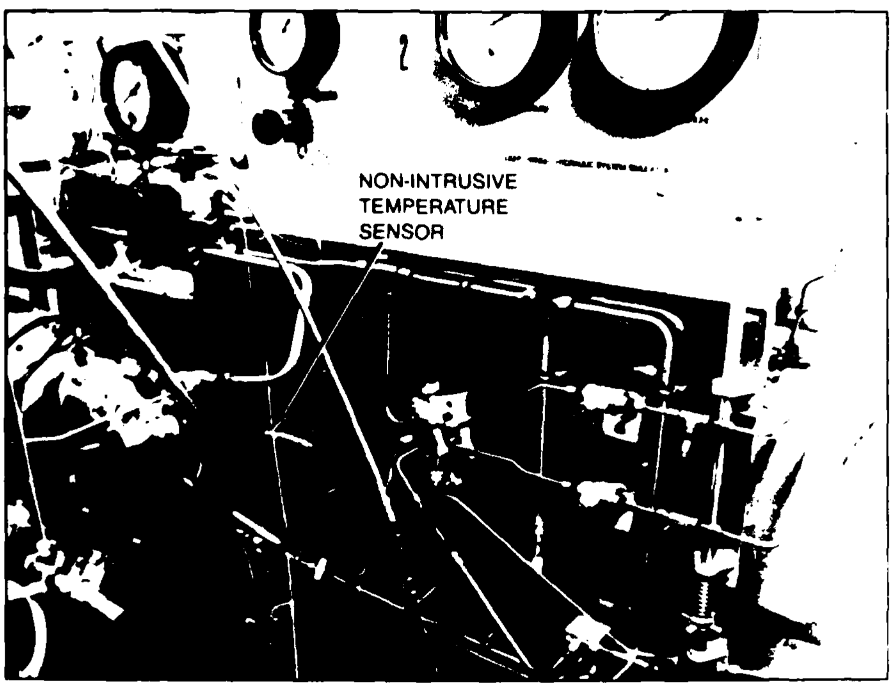


Figure 13b. Non-Intrusive Temperature Sensor

Figure 14. Non-Intrusive Flow Sensor.

The simulator was operated to establish the baseline data points. System pressure, temperature, reservoir level, and system flow were recorded and stored to provide a reference base, in order to establish the point of initiation of the failure. The digital display reads out the system conditions (Fig. 15) and a printout is produced as shown in Appendix D. The external leak was initiated by manually opening the bypass valve and dumping fluid overboard. The non-intrusive flow sensor continuously feeds the microprocessor with the subsystem flow reading during the test.

In addition to the flow input, a position sensor in the reservoir continuously inputs the reservoir level to the microprocessor. The microprocessor used the information provided by the flow and reservoir level sensors to establish the system's performance at all times. The microprocessor was programmed with upper flow limits to establish the point at which a subsystem leak is detected. At that point, the microprocessor signaled the isolation valve to energize and shut down flow to the faulty subsystem. This resulted in termination of the overboard leak and the prevention of total reservoir depletion. In addition, it allowed the remaining portions of the hydraulic system to continue to function.

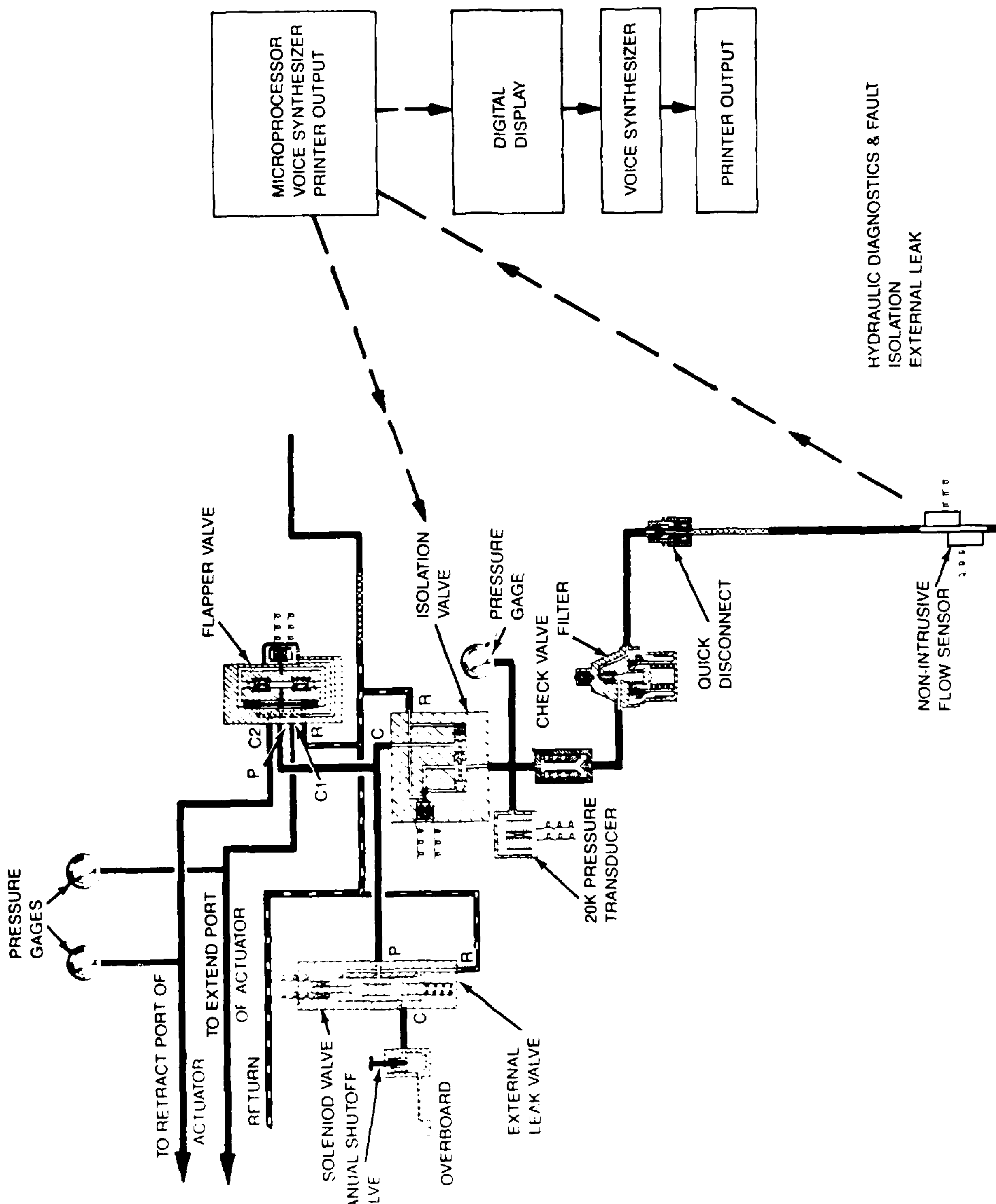


Figure 15. External Leak Schematic.

2.10.2 Subsystem Internal Leak Detection

The hydraulic simulator was modified to incorporate an internal leak valve between the extend and retract ports of the actuator (Fig. 16). In addition, an isolation valve, pressure transducer, and non-intrusive flow sensor were added to provide information on the system parameters for the microprocessor. As experienced with the external leak valve, the internal leak valve failed to provide reliable results. The valve was replaced with a manually operated bypass valve to improve system reliability.

The system was operated to establish the baseline parameters of: system pressure, temperature, reservoir level, and system flow. The digital display provided a readout of the actual system parameters when the system was placed in the ground mode of operation. The internal leak was initiated by manually opening the bypass valve and allowing fluid to pass from the retract side of the actuator to the extend side. The non-intrusive flow sensor will start to record an increase in flow as a result of more flow passing through the isolation valve to compensate for the internal bypass. The reservoir level sensor does not show any noticeable change in position since there is no fluid loss in the system. The microprocessor was programmed with a flow limit to establish the point at which an internal leak was detected in the subsystem. When that limit was reached, the microprocessor signaled the isolation valve to energize and shut down flow to the faulty subsystem. This resulted in termination of the internal leak and permitted full operation of the remaining portions of the hydraulic system.

2.10.3 Servoactuator Open Loop Failure

The servoactuator open loop failure was demonstrated by simulating a break in the feedback signal from the LVDT to the servoactuator amplifier. The failure was initiated by opening a switch in the LVDT cable. The result caused the servoactuator to go hardover; the recorder position trace and the microprocessor indicated this. The shutdown of the fluid flow by the microprocessor complied with the electrical feedback break which caused the servoactuator open loop failure. Branch circuit No. 1 was used to demonstrate the open loop failure (Fig. 17).

2.10.4 Excessive Pump Case Drain Flow Detection

The hydraulic simulator was modified to incorporate an internal leak valve between the pump outlet and the case drain line (Fig. 18) which provided a means by

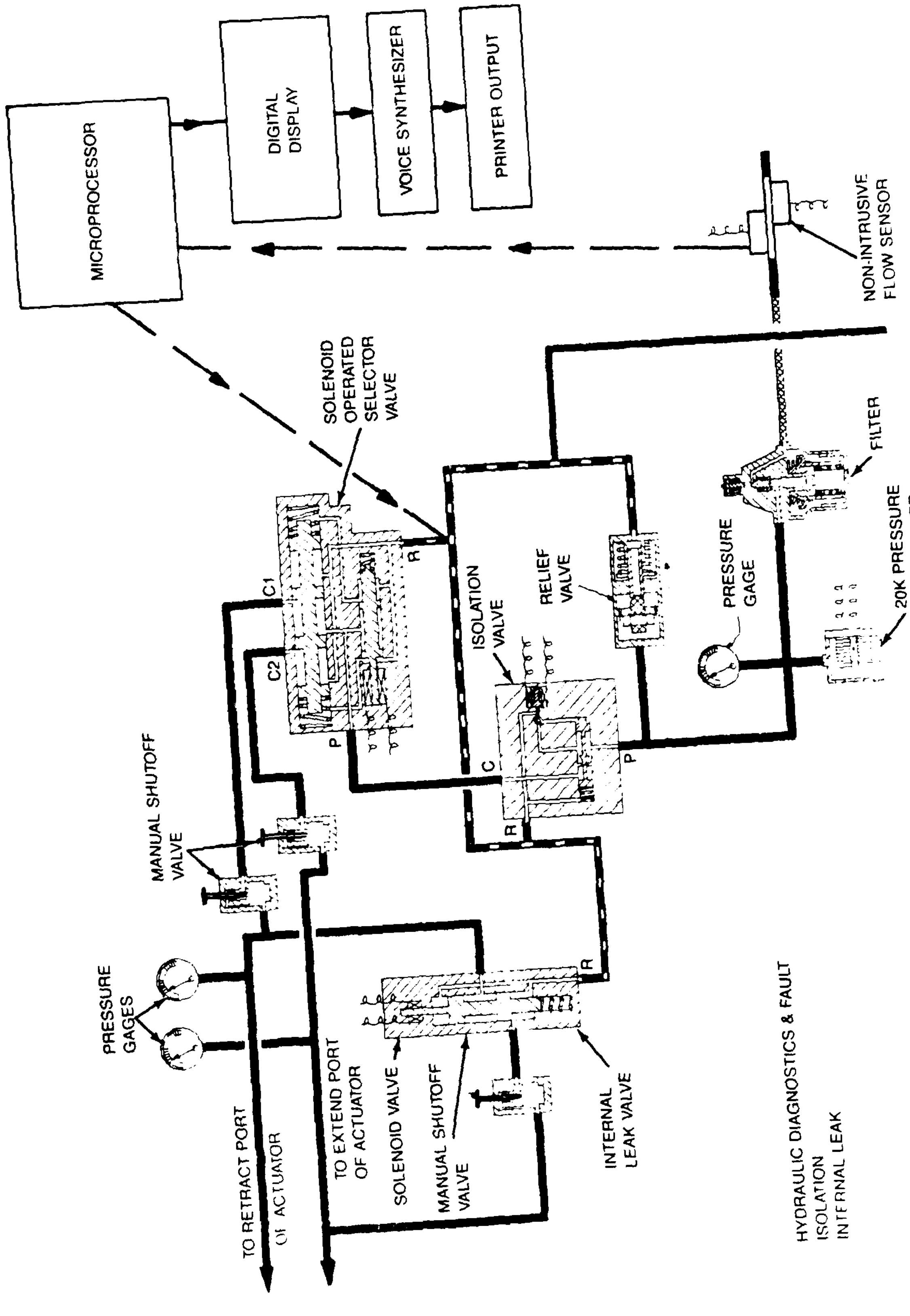


Figure 16. Internal Leak Schematic.

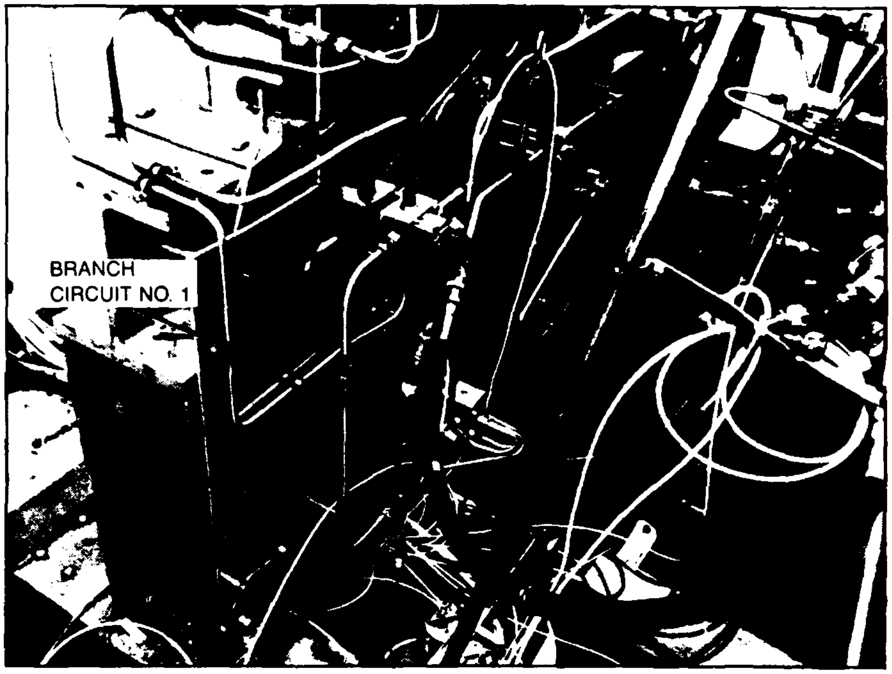


Figure 17. Branch Circuit No. 1 Open Loop Failure.

Figure 18. Excessive Case Drain Flow.

which to add an increased flow into the case drain line. In addition, a non-intrusive flow sensor was added upstream of the case drain filter, and a turbine flow meter was installed downstream of the case drain line heat exchanger (Fig. 19). The system was operated to establish baseline data for the pump case drain flow. The digital display provided a readout of the case drain flow status when in the ground operation mode. The internal bypass was initiated by energizing the internal leak valve and monitored by the flow sensors. The microprocessor compared the current flow information with the baseline. When the flow exceeded the required limit, the printout and digital display record the appropriate failure message.

2.10.5 Excessive Air in the System

In order to demonstrate excessive air in the system, the simulator was first shut down. This allowed air in the system to travel back to the reservoir. The system parameters were recorded by the microprocessor and then the reservoir was repressurized to 50 psi. The microprocessor compared reservoir position and related the increased movement due to an accumulation of air in the reservoir. The microprocessor then displayed an "excessive air in reservoir" signal condition.

2.10.6 Excessive Pump Case Drain Temperature Detection

A temperature above normal case drain temperature (approximately 245°F) was caused by intentionally reducing the cooling water flow to the case drain heat exchanger. The microprocessor programmed to display a "high case drain oil temperature" of 275°F was exceeded and performed properly at the 275°F temperature.

2.11 BOOTSTRAP RESERVOIR

An 8000 psi bootstrap reservoir was designed, fabricated and bench tested for use in Grumman's generic 8000 psi simulator (Fig. 20 a and b).

During the bench testing the reservoir was to be proof pressure tested to 12,000 psi. At approximately 11,500 psi, the head end cap retaining ring started to slip out of its groove. The system was shut down and the reservoir was inspected. The end plate was bent and deformed. The design of the reservoir end plate was reviewed; it was determined that the tolerance between the snap ring clip and the ring circumference was too large. This resulted in the snap ring being able to move out of the groove as the pressure exceeded 11,500 psi, failing the end plate.

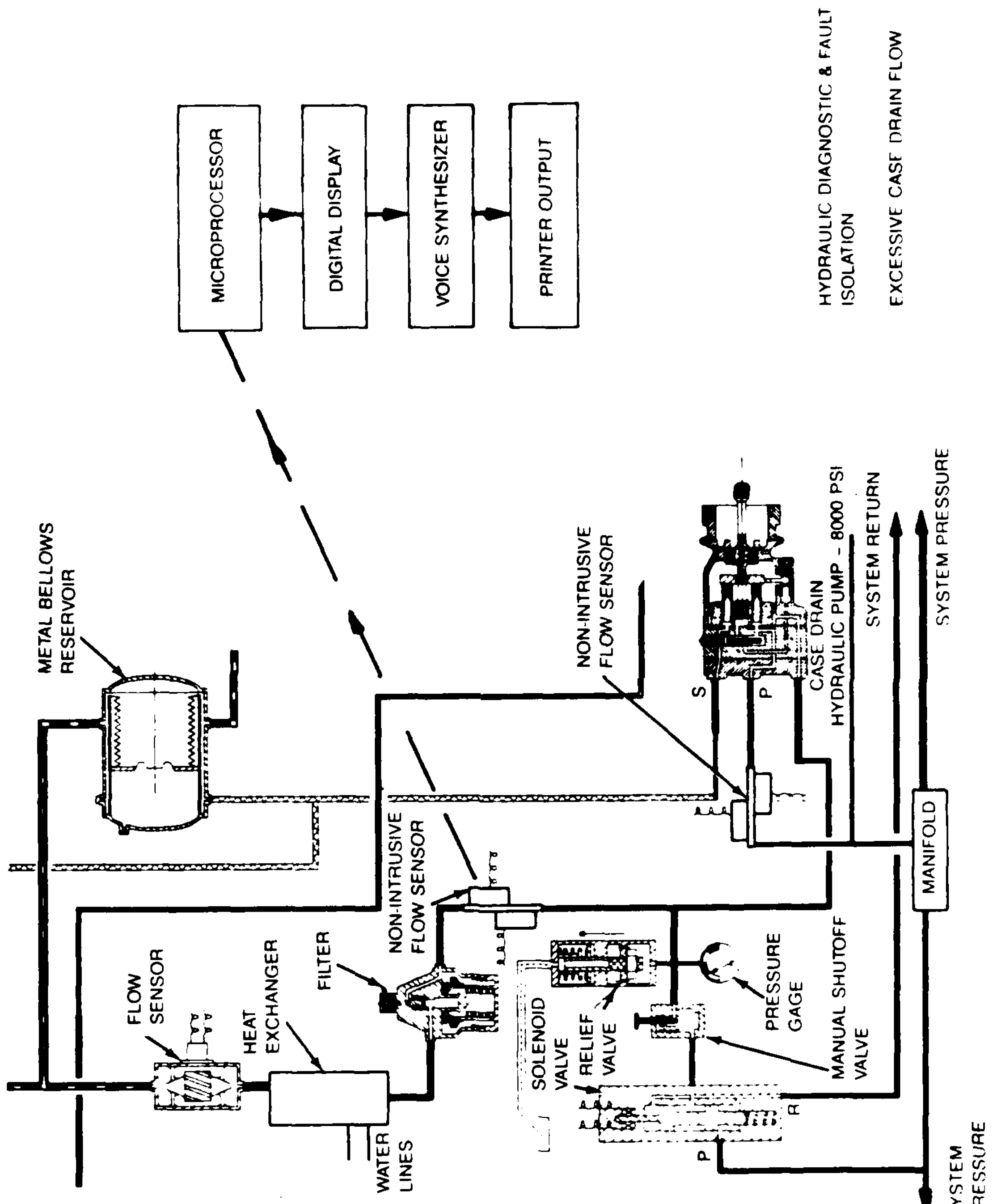
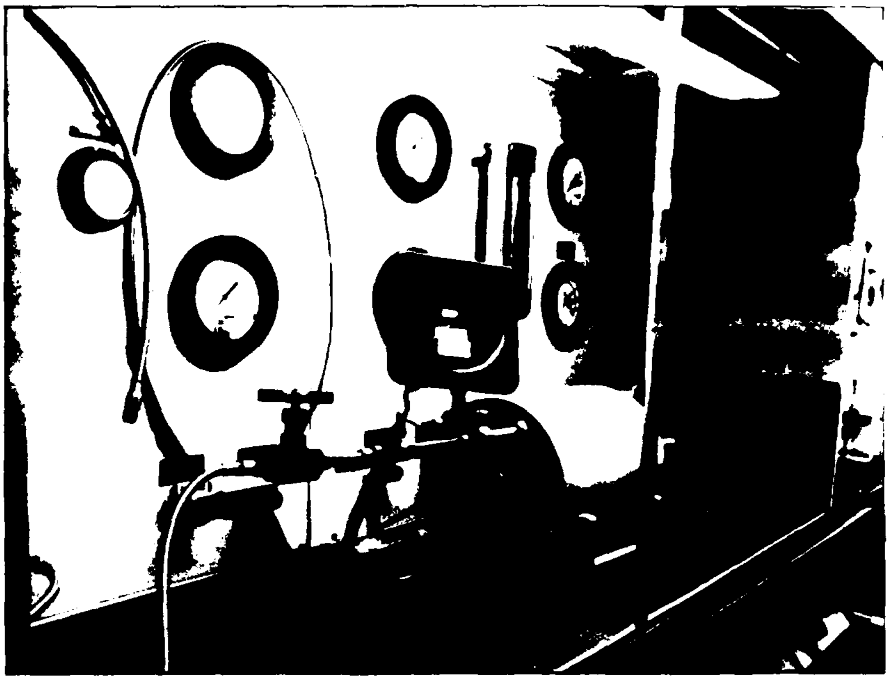


Figure 19. Case Drain Flow Schematic.



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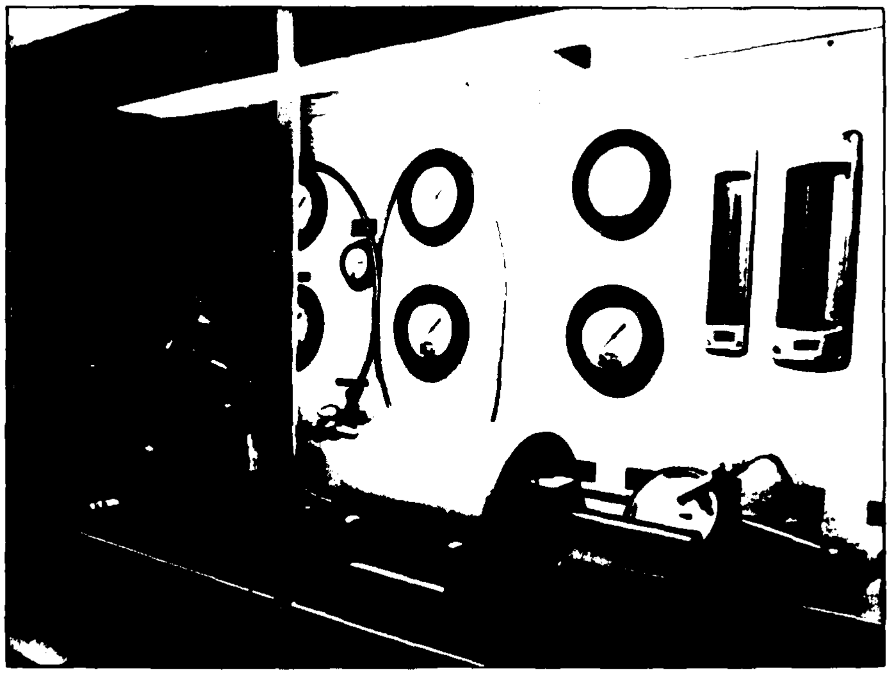

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Figure 20. 8000 Psi Bootstrap Reservoir.

In order to prevent this from occuring, the end plate retaining clips were resized and three additional retaining blocks were added (Fig. 21). The end plate was replaced, new seals were installed and the reservoir was reassembled. The unit was retested and successfully passed the 12,000 psi proof pressure test.

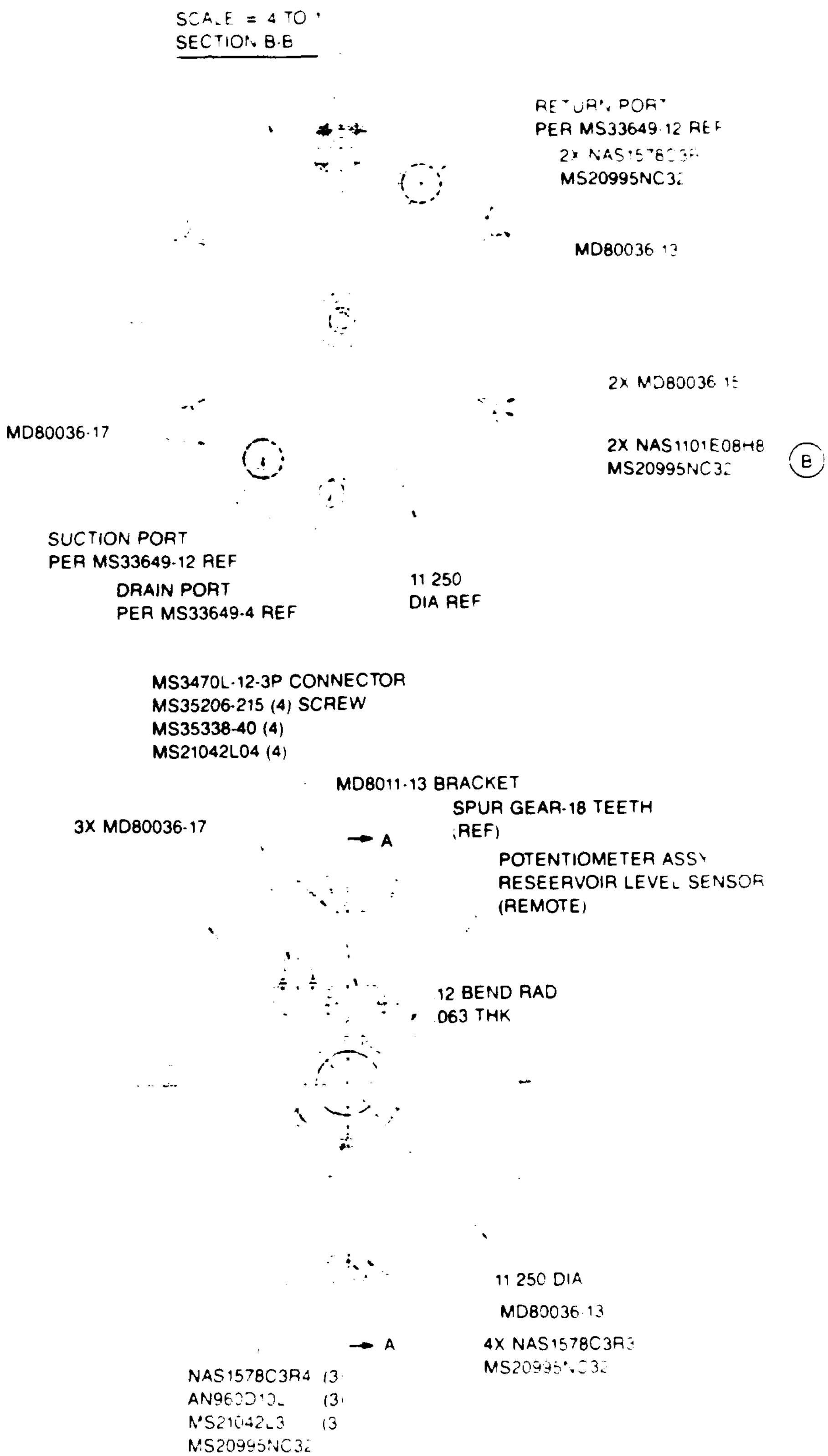

Figure 21. Reservoir Assembly

3 - CONCLUSIONS

The hydraulic diagnostics and fault isolation program has demonstrated that with proper implementation and use of system flow, level and temperature sensors, in conjunction with isolation valves and a microprocessor, a means of detecting system failures and separating the failed branch circuits from the rest of the system can be achieved. This was accomplished without any interference with normal system operation and with no influence on safety of flight.

The advantages gained by the implementation of a diagnostic and fault isolation system are as follows:

- Early detection of a subsystem failure
- Inflight corrective action to enable safe completion of mission and/or safe return to base
- Minimum impact on existing system to incorporate sensors and valves
- Maintenance information to aid the technician in establishing the failed subsystem, minimizing "downtime"
- Aids in ground checkout of aircraft system prior to flight
- The system was able to detect the difference between internal and external leaks.

4 - RECOMMENDATIONS

The hydraulic diagnostic and fault isolation test program demonstrated the feasibility of detecting and isolating various subsystem failures in order to permit the continuing operation of the rest of the hydraulic system. The following is recommended as a continuing effort:

- Develop flight type non-intrusive flow sensors
- Expand capability of microprocessor to record more parameters and vary the response time as needed for each parameter
- Integrate diagnostics with smart pump
- Integrate diagnostics into A-6E aircraft for use as an airborne test bed.

APPENDIX A
TEST PLAN

CONTRACT REQUIREMENTS	CONTRACT ITEM	MODEL	CONTRACT NO.
			N62269-84-C-0289

REPORT

NO. FP-3601-901-108 DATE 3 May 1985

HYDRAULICS DIAGNOSTICS
&
FAULT ISOLATION
TEST PLAN

CODE 26512

PREPARED BY R. L. Kennedy/H. Dreksler

CHECKED BY W. Yearsley

DEPARTMENT

SECTION

TECHNICAL APPROVAL

APPROVED BY J.J. Duzich/P. Marino

APPROVED BY E. Anderson

APPROVED BY

REVISIONS

DATE	REV BY	REVISIONS & ADDED PAGES	REMARKS

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TABLE OF CONTENTS

1.0 INTRODUCTION

This document outlines the laboratory testing of a Fault Detection and Isolation System as installed on three 8000 psi hydraulic system simulators. The testing will be conducted at the Grumman Aerospace Corporation facilities at Bethpage, New York in the Plant 14 Mechanical Test Laboratory.

1.1 Purpose of Test

The purpose of this test is to verify the functional compliance and compatibility of the detection and isolation test article with the applicable design criteria, as well as its suitability for service in a 8000 psi hydraulic system.

1.2 Authorization

This test is in partial fulfillment of Contract No. N62269-84-C-0289.

1.3 Responsibility

In the event of a malfunction of a test article, the test will be stopped immediately and the cognizant design engineer will be notified by the test engineer. The cognizant engineer will determine the cause of the failure and then determine corrective action.

1.3.1 Data acquisition and instrumentation shall be provided by the Corporate Instrumentation Dept.

2.0 DESCRIPTION OF TEST ARTICLE

2.1 General-

System Description

Hydraulic System-

The fault detection and isolation test arrangement consists of three high pressure lightweight aircraft hydraulic system simulators. The three simulators operate at 8000 psi and are supplied by one 14 GPM, 8000 psi aircraft hydraulic pump which is driven by a 75 horsepower electric vari-drive unit.

Each simulator consists of an 8000 psi hydraulic actuator that is loaded to simulate an aircraft flight control system load. There are two electro-hydraulic servo valves and one three position solenoid valve used as cycling devices for the high pressure actuators. Two of the three hydraulic system simulators will employ the servo valves and the third simulator will use the solenoid valve. Other components of the simulators consist of 8000 psig relief valves, accumulator, check valves, quick disconnects, filters and flex hoses. Other components include heat exchangers, hydraulic swivels (8 ksi), coiled tubing (8 ksi), and titanium tubing. Two hydraulic reservoirs will be used, in turn, in the return side of the simulators (only one at a time) for comparative purposes. One is a metal bellows type and the second is a bootstrap type reservoir. The bootstrap reservoir is designed for high pressure use (8000 psi). Linear Variable Differential Transformers (LVDT's) are to be used in conjunction with the servo valve actuators for two purposes. One is to mark the position of the actuator piston and two, to maintain a closed loop by performing the actuator feedback function.

Instrumentation consists of a 25,000 lb. force link attached to the piston rod of the load cylinder, a 20,000 psi pressure transducer at the pump outlet pressure to the test rigs, flow measuring of pump outlet, pump case drain and other pertinent flows, an assortment of pressure gages, thermocouples, and pressure, flow and temperature recorders.

All components are tested on a Grumman Aerospace Corporation high pressure test bench to the appropriate proof pressures (12000 psi) before being installed on the simulators. All tests will be conducted using MIL-H-83282 hydraulic fluid.

2.2 Component Definitions-

2.2.1 DC-Operated Linear Variable Differential Transformer (LVDT)
2.2.2 Isolation Valves 3-way 2-position
2.2.3 Directional Control Valves 2-way 2-position
2.2.5 Flow Sensors
2.2.5.1 Sonic Flowmeters
2.2.6 Electrohydraulic Servo Valve
2.2.7 4-Way 3-position Solenoid Valve
2.2.8 Reservoir Potentiometer

2.2.1 DC-Operated Linear Variable Differential Transformer

Manufacturer: Shaevitz Engineering, Camden, New Jersey
Series: HCD
Model: 5000
Engineering Specifications:

Range:	±5.00 inches
Sensitivity:	2.0 volts per inch
Linearity:	±.21% of full range
Output Load:	.5 megomms
Input Voltage:	±15 VDC
Core Length:	6.20 inches
Core Diameter:	.188 inches (outside)

2.2.2 Isolation Valve 3-way - 2-position normally open 8000 psi
Teledyne Hydra-Power
Model No.: HP1479100-1
Specifications:

1. Pressures:

	P & C Ports	R Port
Rated:	8000 psi	100 psi
Proof:	12000 psi	8000 psi
Burst:	16000 psi	12000 psi

2. Hydraulic Fluid: MIL-H-83282
3. Leakage: Internal: De-Energized: (P&R or C to R): 10cc/min (10 drops/3 min)
   Energized: (P to C or P to R): 1cc/min (1 drop/3 min.)
   External: Zero
4. Temperature Range: -65°F to +275°F
5. Rated Flow: 5.7 gpm
6. Pressure Drop: 50 psi at 5.7 gpm & 70°F to 110°F
7. Response Time: 10 milliseconds
8. Electrical: Operating Voltage: 28 vdc
   Minimum Pull In: 17 vdc at 70°F
   Dropout Voltage: 2-7 vdc
   Current Drain: 1.0 amps at 29 vdc & 70°F
   Duty Cycle: Continuous

2.2.3 Directional Control Valve (2-way- 2-position) normally open 8000 psi Part MP 1480100-1 (Internal Leakage Valve)

Specifications- 1. Pressures:

	C_1 C_2 Ports	R Ports
Operating:	8000 psi	100 psi
Proof:	12000 psi	8000 psi
Burst:	16000 psi	1200 psi

2. Hydraulic Fluid: MIL-M-83282
3. Leakage: Internal: De-Energized: with 8000 psi at C_2 leakage at C_1 C_3 & R2 drops per min. (max.)

Energized: with 8000 psi at C_1 C_2 & R2 drops per min. (max.)

External: Zero

4. Temperature: Normal operating fluid 140°F to 180°F extreme environmental conditions - 50°F to 275°F

5. Electrical: Operating Voltage: 17 vdc to 30 vdc
Duty Cycle: Continuous per MIL-S-4040
Current .75 amp (max.) at vdc & 70°F

2.2.4 Directional Control Valve (3-way, 2 position) normally closed, 8000 psi. P/N HP 1479100 Manufacturer: Teledyne Hydra-Power

Specifications:

1. Pressure:

Pressure:	P&R Ports	R Ports
Operating:	8000 psi	100 psi
Proof	12,000 psi	8000 psi
Burst	16,000 psi	12000 psi

2. Hydraulic fluid: MIL-H-83282

3. Leakage, Internal De-energized: 1 drop/3min with 8000 psi @ Press. port
Energized: 1 drop/3 min. with 8000 psi @ press. port with the cyl. port blocked
External: Zero

4. Temperature: normal operating, fluid +140° to +180°F extreme environmental conditions -50°F to +275°F

5. Electrical: operating voltage: 17 VDC to 30 VDC duty cycle: continuous per MIL-S-4040. Current: .75 amps max. @ 30 VDC & 70°F

2.2.5 Flow Sensors

2.2.5.1 Sonic - Controlotron Corporation- (non-intrusive flow metering system for Grumman)

Factor	Standard CC System 960
Linearity	0.1%
Sensitivity	.001 ft./sec.
Flow Range	-40 ft./sec. to +40 ft./sec including zero flow
Pipe/Tube Size Cap.	¼" to 156" OD
Accuracy	0.5% to 1.5%
Pressure Drop	Zero
Response Time	10 milliseconds to 1 second (adjustable)
Repeatability	.01 ft./sec. (1. min. ave.)
Hysteresis	Zero
Built-in-test	Standard
Fault Monitor	Standard
Test Connector	BNC connection
On Site Calibration Test	Available
Signal Format	Any desired-Digital and/or - Analog
Transducer Temp. Capability	-65°F to +500°F
Flow Computer Temp. Capability	-40°F to +135°F

2.2.6 Electro-hydraulic Servo Valve Abex Corp. Model 415-1971

Engineering Specifications:

Rated Flow: 10 gpm at 1000 psi drop
28 gpm at 8000 psi drop

Operating Pressure: 8000 psi

Hysteresis: .3 MA max.

Threshold: .03 MA max.

Null Bias: .12 MA max.

Input Signal: 8 MA

Null Leakage: .4 gpm at 3000 psi supply
.65 gpm at 8000 psi supply

Electrical Lead Wire: 4 wire pigtail

Temperature: -65°F to +275°F

2.2.7 4-Way - 3-Position Solenoid Valve Bendix Model:3321472

Specifications

Operating Pressure: 8000 psi

Proof Pressure: 12,000 psi

Burst Pressure: 16,000 psi

Fluid Temperature: -50°F to +275°F

Fluid Media: MIL-H-83282 Hyd. Fluid

Rated Flow: 4.5 gpm at 50 psi max. pressure drop

Solenoid Operating Voltage: 29 vdc max. and 1 amp. max.
at 70°F
designed 1 AW MIL-S-4040 Type 1

Solenoid Resistance: 85 to 90 ohms at 70°F to 90°F (ref.)

2.2.8 Reservoir Potentiometer

Bourns Potentiometer

Bushing Mount Precision Potentiometer

10-Turn-Wire Wound Model 3500 S-2

Engineering Specifications:

Resistance: 20,000 ohms

Exceeds Humidity Requirement MIL-DR-12934

Power: 2 Watts at 70°C

Absolute min. Resistance: 1 ohms or 0.1%, whichever is greater

Independent Linearity: ±0.20%, Oper. Temp. 125°C max.

Tolerance: ±3%, Size: 7/8" diameter x 1" length, Shaft: ¼" diameter

Thread Interface: 3/8 - 32 UNEF 2A

Operating Temp. Range: 65°F to 255°F

Torque: 0.60 oz. in. max.

Weight: 1.0 oz. maximum

3.0 DESCRIPTION OF TESTS

3.1 Tests and Sequence- The types of tests to be run are as indicated in the paragraphs below. They are not necessarily listed in the order in which they are to be performed. The test engineer is responsible for the sequence of the testing. Details of each test are as described in the Test Procedures, paragraph 4.0.

3.2 Test Conditions

3.2.1 Test Fluid- Tests will be conducted using hydraulic fluid conforming to spec. MIL-H-83282 continuously filtered through a 5 micron filter (or finer) absolute non-bypass filter.

3.2.1 Temperature- Except where otherwise specified, the tests will be conducted at an ambient temperature of 70° to 90°F and a fluid temperature of 70° to 275°F.

3.2.2 Pressure- Operating pressure will be 8000 psig and proof pressure will be 12,000 psig. Unless otherwise specified, tolerance on all pressures shall be ±5%.

3.2.3 Bleeding- Before commencing tests the system shall be leak checked and bled to ensure elimination of air from all system and device cavities.

4.0 TEST PROCEDURES

4.1 High Flow Subsystem External Leak Detection, Display and Isolation Test

This test will be performed on branch circuit number three. A high flow external leak of one (1) gallon per minute will be initiated in the hydraulic fluid supply line to the servo valve by opening a solenoid valve which allows the hydraulic fluid to flow overboard through a pre-set restrictor valve. This leak will cause the flow sensor on the hydraulic supply line to number three branch circuit to indicate a higher than normal flow and hence trigger the isolation solenoid valve on the number three branch circuit hydraulic supply line to the shut position and thereby stop the external leak. A microprocessor will sense both the high flow and the system reservoir level and will display an external leak when both signals are in the proper relationship to normal conditions.

4.2 Low Flow Subsystem External Leak Detection, Display and Isolation Test

This test will be performed on branch circuit number three. A low flow external leak of 0.5 gallon per minute will be initiated in the hydraulic fluid supply line just upstream of the servo valve by opening a solenoid valve which allows the hydraulic fluid to flow overboard through a pre-set restrictor valve. The flow sensor on the number three branch circuit hydraulic fluid supply line will sense and display a slightly higher than normal fluid flow rate and cause the number three branch circuit isolation solenoid valve to close and shut off the hydraulic fluid supply thus stopping the overboard leak. A microprocessor senses both the fluid flow and the system reservoir level and based on an increase in flow and a decrease in reservoir level an external leak will be displayed.

4.3 Internal System Leakage Detection, Display and Isolation

Internal leakage across the 8000 psi actuator piston will be demonstratrd on branch circuit number two. A solenoid valve that allows flow in either direction is in series with a pre-set restrictor valve between the two actuator hydraulic supply lines. The restrictor is pre-set to 1 gallon per minute. The solenoid will be activated to the open position. This will allow an increase in the total hydraulic fluid flow to branch circuit number two. The flow sensor will display this and the branch circuit number two isolation valve will be triggered to shut off the supply of hydraulic fluid. A microprocessor will sense both the increased fluid flow and the system reservoir level to determine whether an external leak or an internal leak is causing the high flow and then display the proper signal.

4.4 Servo Actuator Open Loop Failure Detection and Display

This open loop failure will be demonstrated by simulating a broken (open) wire in the feedback cable from the linear variable differential transformer (LVDT) to the servo actuator amplifier. The number one branch circuit will be used for this test. The open loop failure will be initiated by opening a switch in the LVDT cable. This will cause the servo actuator to go hardover. The position trace on the recorder and to the micro-processor will indicate this. A no fluid flow signal to the microprocessor coupled with this will cause a display of "servo actuator open loop".

4.5 Excessive Pump Case Drain Flow Detection and Display

A high pump case drain flow will be implemented by bleeding hydraulic fluid from the pump outlet manifold, through a solenoid operated shutoff valve, then through a pre-set restrictor valve tied into the case drain line upstream of the case drain flow sensor.

The solenoid shutoff valve will be activated to the open position, the flow sensor will indicate a higher than normal case drain flow into the microprocessor for display when the system is queried in the ground mode.

4.6 Excessive Air in System, Detection and Display

A normal range of hydraulic fluid level in the system reservoir while operating the system in a normal mode will be established. Excessive air will be injected into the oil side of the reservoir while the system is not operating so that when the system is started a consistently higher than normal reservoir fluid level will be sensed by the reservoir bellows position potentiometer. This signal will trigger the microprocessor to display an "air in reservoir" display when queried while in the ground mode.

4.7 Excessive Pump Case Drain Temperature Detection and Display

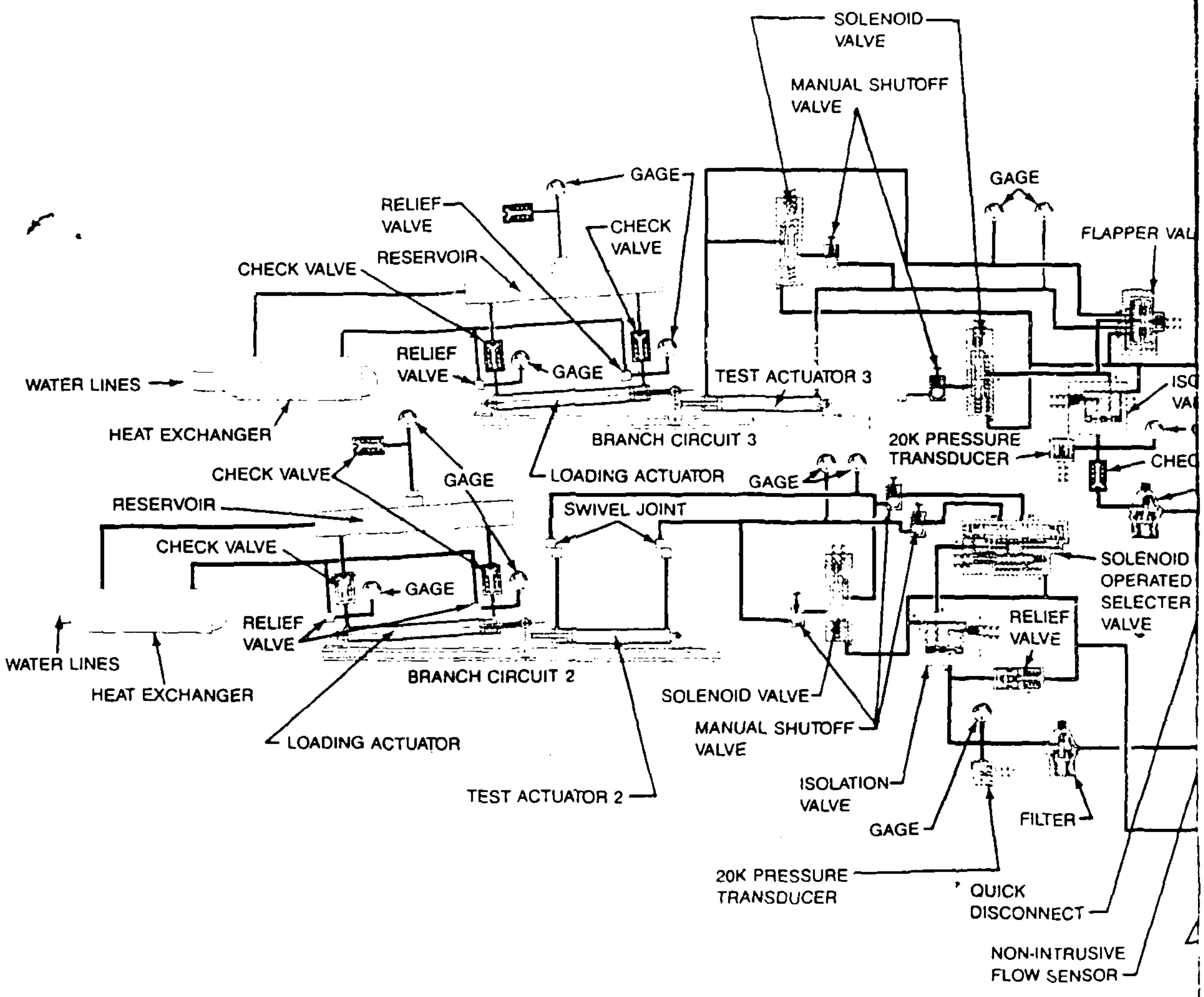
A temperature above a normal case drain temperature (approximately 245°F) will be caused by intentionally reducing the cooling water flow to the case drain heat exchanger. The microprocessor will be programmed to display a "high case drain oil temperature" when 275°F has been reached. This data is displayed in the "ground" mode of the microprocessor.

5.0 TEST COMPONENT AND TEST DATA DISPERSAL

Upon satisfactory completion of all testing, the three isolation valves manufactured by Teledyne Hydra-Power under part number HP 1477100 will be delivered to the Naval Air Development Center (NADC). The bootstrap reservoir designed by Grumman Aerospace Corporation for use with an 8000 psi system will also be tested and delivered to NADC. The reservoir part number is MJE000. (S/N 002).

The test results will be summarized in a test report and submitted to NADC.

APPENDIX B
HYDRAULIC DIAGNOSTICS & FAULT ISOLATION SYSTEM SCHEMATIC


SOLENOID VALVE
MANUAL SHUTOFF VALVE
GAGE
GAGE
FLAPPER VAL
RELIEF VALVE
CHECK VALVE
RESERVOIR
CHECK VALVE
RELIEF VALVE
GAGE
WATER LINES
TEST ACTUATOR 3
HEAT EXCHANGER
BRANCH CIRCUIT 3
20K PRESSURE TRANSDUCER
CHECK VALVE
GAGE
LOADING ACTUATOR
GAGE
RESERVOIR
SWIVEL JOINT
CHECK VALVE
GAGE
SOLENOID OPERATED SELECTER VALVE
RELIEF VALVE
RELIEF VALVE
WATER LINES
HEAT EXCHANGER
BRANCH CIRCUIT 2
SOLENOID VALVE
MANUAL SHUTOFF VALVE
LOADING ACTUATOR
ISOLATION VALVE
TEST ACTUATOR 2
GAGE
FILTER
20K PRESSURE TRANSDUCER
QUICK DISCONNECT
NON-INTRUSIVE FLOW SENSOR

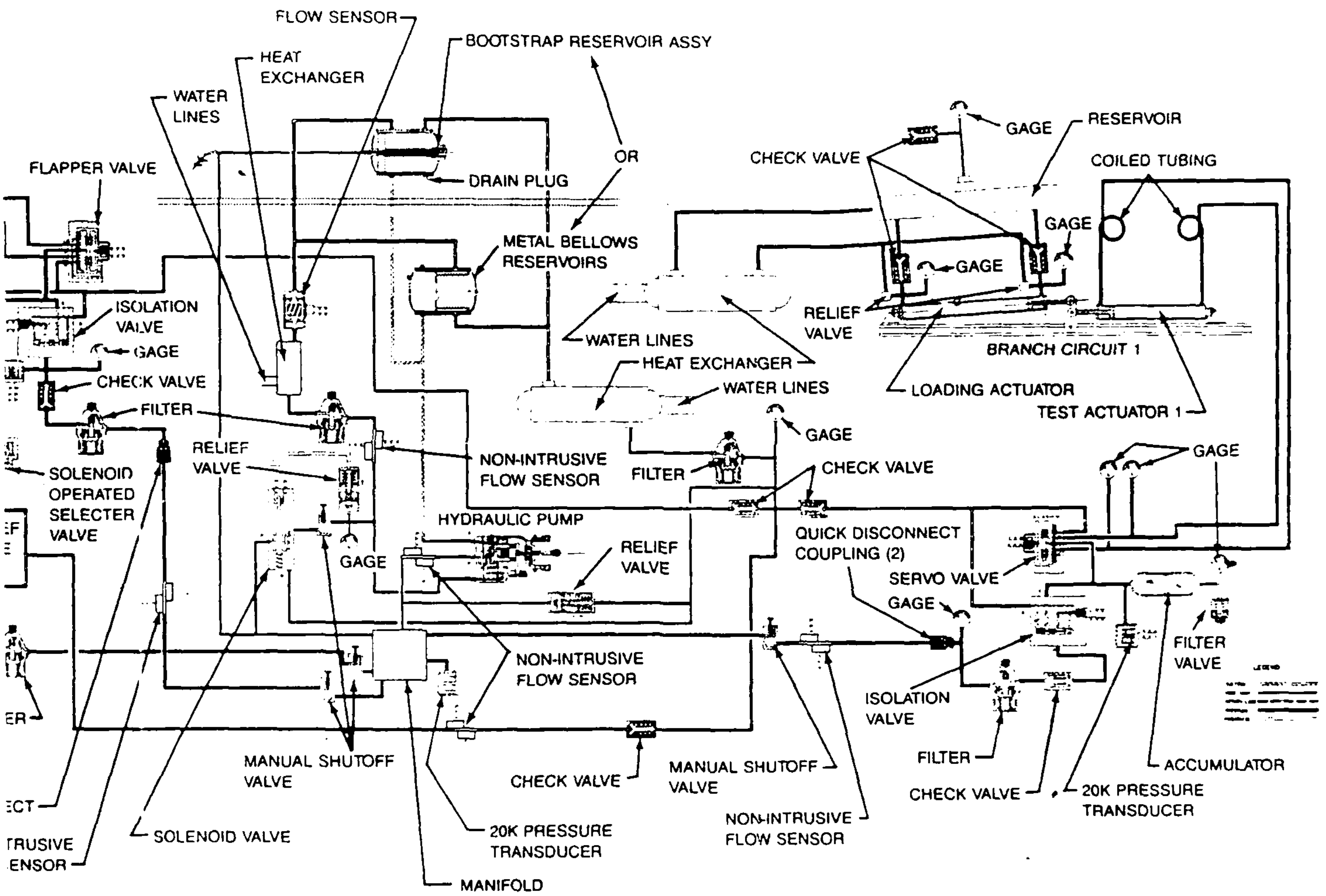


Figure B-1. Hydraulic Diagnostics & Fault Isolation System Schematic

APPENDIX C
BRUSH CHART RECORDINGS

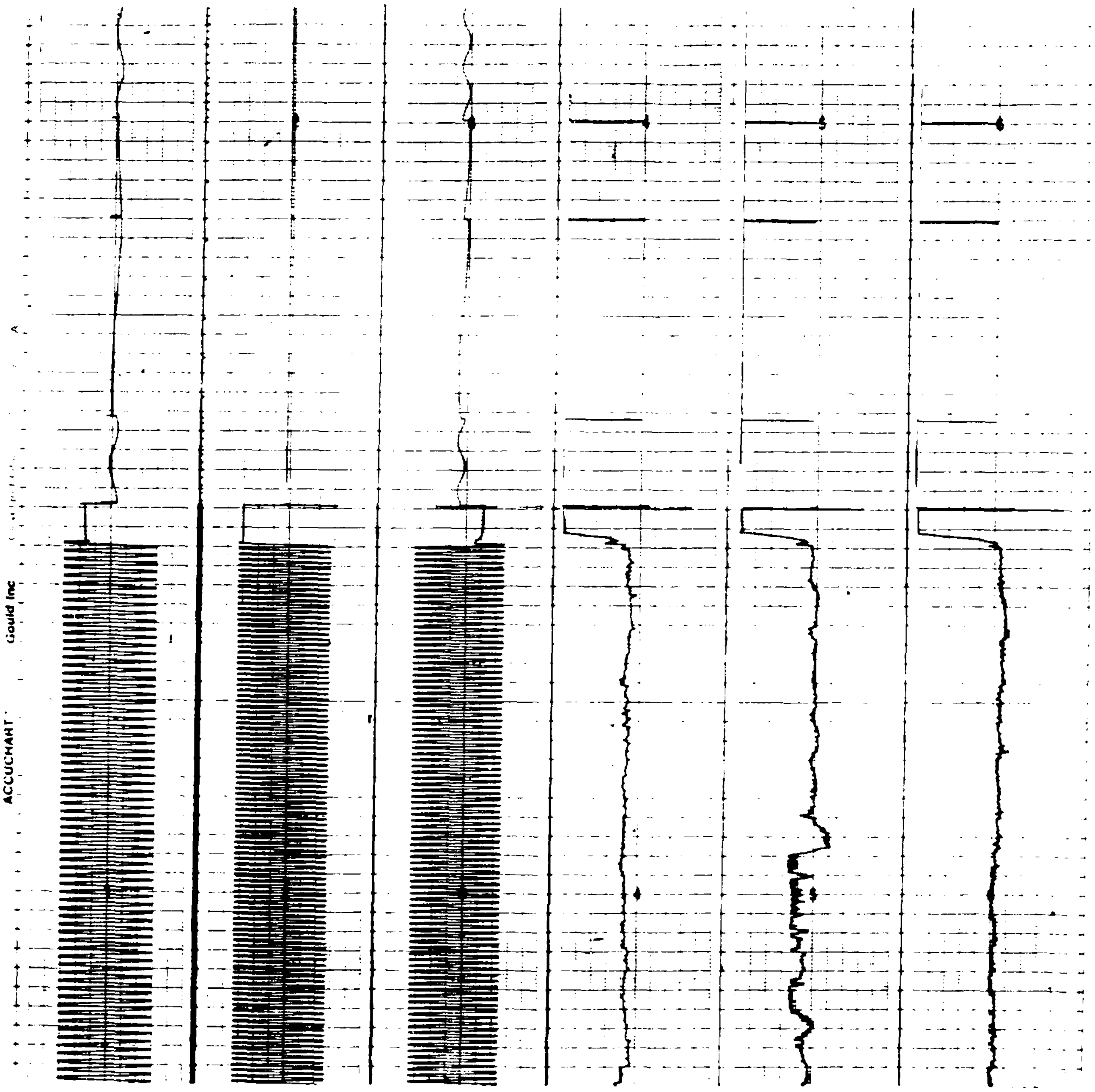


Figure C-1 Brush Chart Recordings

APPENDIX D
SAMPLE PRINTOUT

```
Warning- temp above 190 F .
 Pressure over 5000 PSI - OK.
Warning - low reservoir level.
    Rig 1 OK - normal flow.
External leak-rig 2 valve off.
Internal leak-rig 3 valve off.
Warning- high case drain flow.

 Warning- temp above 190 F .
 Pressure over 5000 PSI - OK.
Warning - low reservoir level.
    Rig 1 OK - normal flow.
External leak-rig 2 valve off.
Internal leak-rig 3 valve off.
Warning- high case drain flow.

 Warning- temp above 190 F .
 Pressure over 5000 PSI - OK.
Warning - low reservoir level.
    Rig 1 OK - normal flow.
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Internal leak-rig 3 valve off.
Warning- high case drain flow.

 Warning- temp above 190 F .
 Pressure over 5000 PSI - OK.
Warning - low reservoir level.
    Rig 1 OK - normal flow.
External leak-rig 2 valve off.
Internal leak-rig 3 valve off.
Warning- high case drain flow.

 Warning- temp above 190 F .
 Pressure over 5000 PSI - OK.
Warning - low reservoir level.
    Rig 1 OK - normal flow.
External leak-rig 2 valve off.
Internal leak-rig 3 valve off.
Warning- high case drain flow.

 Warning- temp above 190 F .
 Pressure over 5000 PSI - OK.
Warning - low reservoir level.
    Rig 1 OK - normal flow.
    Rig 2 OK - normal flow.
Internal leak-rig 3 valve off.
Warning- high case drain flow.
```

Figure D-1 Sample Printout

END
DATE
FILMED
MARCH
1988
DTIC